GEOPHYSICAL SURVEYS FOR GROUND WATER EVALUATION SOUTH KONA, ISLAND OF HAWAII

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GROUND WATER EVALUATION
SOUTH KONA, ISLAND OF HAWAII

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(BGI Project No. 91021)

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1.0 INTRODUCTION

Time domain electromagnetic (TDEM) geophysical surveys were performed between April 22 to May 4, 1991 on the Island of Hawaii by Blackhawk Geosciences, Inc. (BGI) for Cal-Pacific International, Inc. (CPI). The surveys were conducted to assist in the evaluation of ground water resources in the vicinity of the 1950 Kaapuna lava flow which is located approximately 17 miles south of Captain Cook, Hawaii.

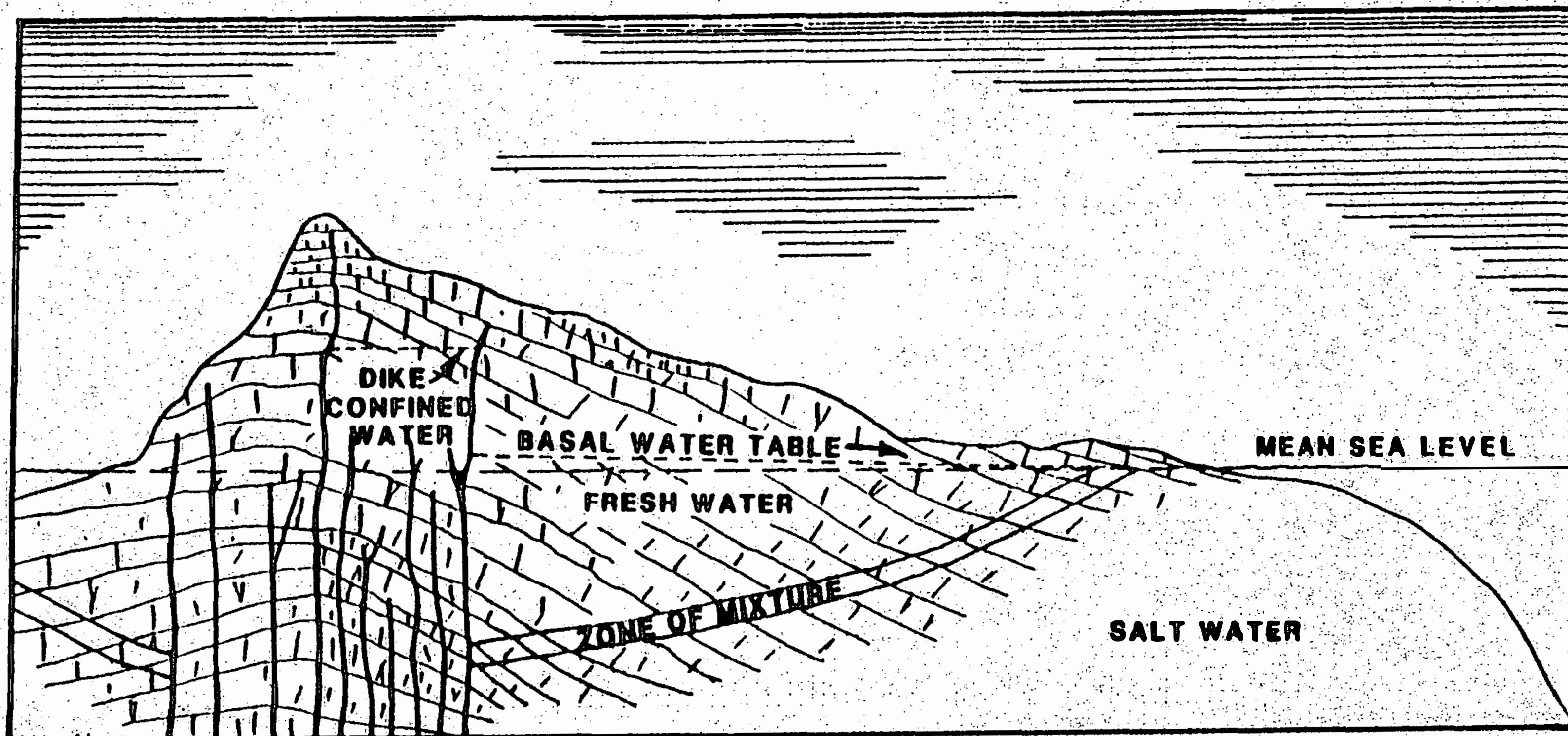
The objective of the geophysical survey was to determine the elevation and thickness of the lens of fresh water floating on salt water. The basis for surface geophysical surveys for ground water evaluations on volcanic islands can be explained with the use of Figure 1-1. The fresh water in these island settings is generally found in two occurrences:

1. <u>Basal fresh water</u>. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a balance is reached where a lens of fresh water floats on sea water. In cases of hydrostatic equilibrium, the Ghyben-Herzberg principle states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

2. <u>Dike-confined waters</u>. Typically, above the rift zone intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

The main ground water occurrence on this property is expected to be in the basal mode. Because the electrical resistivity of rock formations is highly dependent upon the salinity of ground water, electrical surface geophysical techniques can map the depth to salt water, and the thickness of the fresh water lens can then be estimated using the Ghyben-Herzberg principle.

The impetus for using geophysics is that the cost of a geophysical sounding is about one-thousandth the cost of completing a well at elevations above 1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths. The specific geophysical method employed was TDEM soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.



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SCHEMATIC HYDRO-GEOLOGIC CROSS SECTION

CAL-PACIFIC INTERNATIONAL, INC.
South Kona, Island of Hawaii

PROJECT NO: 91021 **Figure 1-1**

2.0 LOGISTICS AND DATA ACQUISITION PROCEDURES

2.1 GENERAL

The TDEM survey was accomplished by a four man crew consisting of two BGI personnel and two local temporary field helpers. The locations of the TDEM soundings were determined from the results of a prior geophysical survey conducted west of State Hwy 11 for CPI during May 1990 and consultation with CPI personnel and their hydrogeologists and consultants. The majority of TDEM measurements for this survey were made east of Hwy 11 above the 1,400 ft elevation level. The TDEM sounding locations for this survey and the May 1990 survey are shown on Figure 2-1. The results of the May 1990 survey are contained in Appendix A and have also been incorporated in this report.

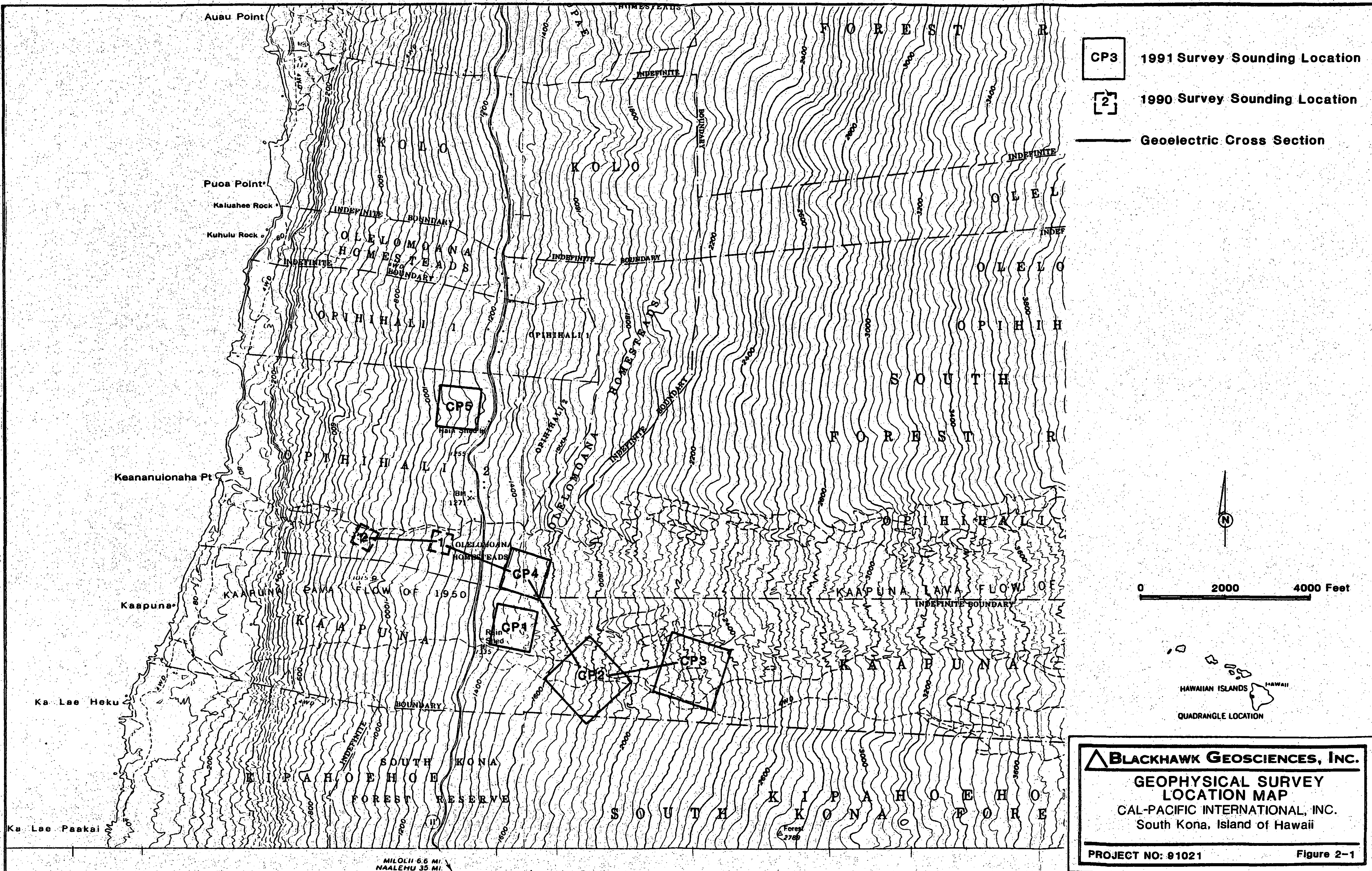
During the five days of field work a total of 5 soundings were acquired on and north of the Kaapuna flow. Sounding locations were surveyed using a compass and hip chain from known landmarks (i.e., road junctions, rain sheds) located on the field maps. Sounding center elevations were measured with an altimeter in the field and checked with USGS maps. Transmitter loop sizes of 1,500 ft by 1,500 ft where used at higher elevations (above 1,600 ft) to detect the salt water interface. A daily log of field activities is given in Table 2-1.

2.2 PROCEDURES

The Geonics EM-37 TDEM system was utilized on this survey. The system basically consists of a transmitter and a receiver. The transmitter loop is constructed of 10 to 12 gauge insulated copper wire. The wire is laid on the ground surface in a square loop varying in size, depending upon the required depth of investigation (larger loop sizes for deeper measurement). A transmitter and motor generator are connected into the non-grounded loop at one corner. A time-varying current is pulsed through the wire at two different base frequencies. The TDEM receiver measures and records the decay of the vertical magnetic field through a receiver coil placed at the center of the non-grounded transmitter loop. Receiver coils with effective areas of 100 m^2 and 1,000 m^2 were utilized at base frequencies of 3 Hz and 30 Hz. During data acquisition numerous transient decays are collected with the receiver for each sounding. Readings were acquired at several receiver gains with opposite receiver polarities for each sounding location. The readings were stored in a DAS-54 solid state data logger, and were nightly transferred to a personal computer for processing. A technical note is given in Appendix B which describes and illustrates the principles of TDEM.

Table 2-1. Daily log of field activities

Date (1991)	Activity
April 22	Mobilize from Denver, CO to Kailua-Kona, HI in conjunction with other surveys.
April 23	Conduct field reconnaissance of property. Found locked gates, poor access to site. Acquire data on sounding CP1 near rain shed.
April 24	Acquire data on sounding CP2.
April 25	Acquire data on sounding CP3.
May 1	Acquire data on sounding CP4.
May 3	Layout transmitter loop for sounding CP5 in PM. One-half day of field work.
May 4	Acquire data on CP5. Reconnaissance for additional sounding sites upslope from CP5 prove to be unaccessible due to property ownership limitations. One-half day of field work.
May 7	Demobilize equipment and BGI personnel.
	(April 26 through 30, and one-half day on May 3, and full days on May 5 and 6 were field work on other Hawaii jobs).



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GEOPHYSICAL SURVEY LOCATION MAP

CAL-PACIFIC INTERNATIONAL, INC.

South Kona, Island of Hawaii

PROJECT NO: 91021 Figure 2-1

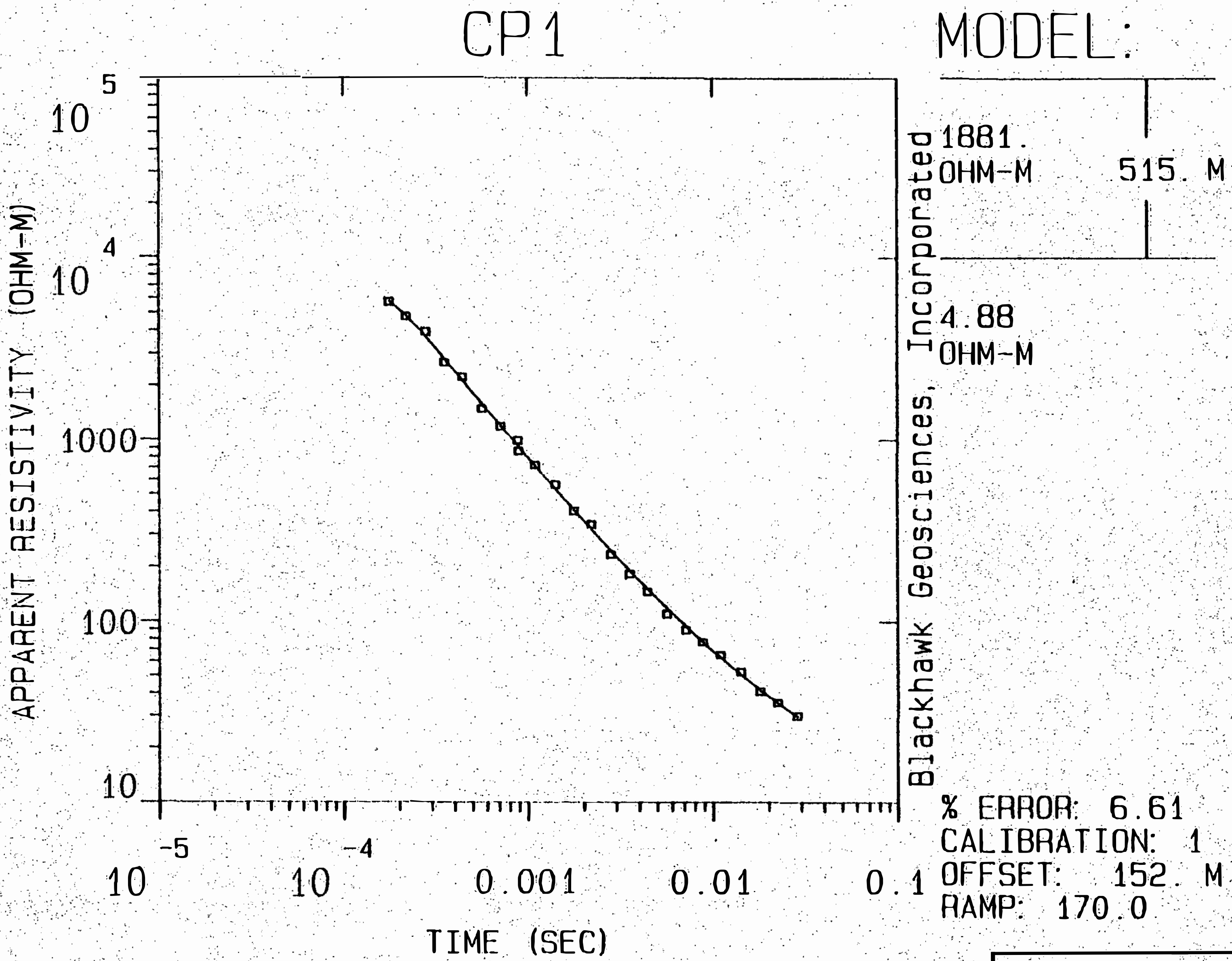
3.0 DATA PROCESSING

The field data acquired each day was transferred from the DAS-54 data logger to a personal computer. The data for each sounding location is edited and combined (both 3 Hz and 30 Hz frequencies) to produce a transient decay curve. This decay curve is transformed into an apparent resistivity curve, which is entered into an Automatic Ridge Regression Transient Inversion Program (ARRTI). From the apparent resistivity curve a one-dimensional model of resistivities and thicknesses is calculated.

The inversion program requires an initial estimate of the geoelectric section, including the number of layers, and the resistivities and thicknesses of each of the layers. The program then adjusts these parameters so that the model curve converges to best fit the curve formed by the field data set. The inversion program does not change the total number of layers within the model, but allows all other parameters to float freely.

An example data set is given in Figures 3-1 and 3-2 for sounding CP1. Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Figure 3-2 is the inversion table and it lists in column 4 the error between measured and computed data in each time gate.

The apparent resistivity curves and data sheets for all of the CPI soundings are contained in Appendix C.



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EXAMPLE DATA SET

CAL-PACIFIC INTERNATIONAL, INC.

South Kona, Island of Hawaii

PROJECT NO: 91021 **Figure 3-1**

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		445.0	1460.0		
1881.22	515.2	-70.2	-230.3	0.3	0.3
4.88					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.77E-04	5.71E+03	5.79E+03	-1.281	
2	2.20E-04	4.77E+03	4.79E+03	-0.247	
3	2.80E-04	3.92E+03	3.69E+03	6.364	
4	3.55E-04	2.68E+03	2.79E+03	-3.933	
5	4.43E-04	2.23E+03	2.13E+03	5.041	
6	5.64E-04	1.49E+03	1.58E+03	-5.967	
7	7.13E-04	1.18E+03	1.19E+03	-0.554	
8	8.81E-04	9.89E+02	9.23E+02	7.177	
9	8.90E-04	8.63E+02	9.11E+02	-5.294	
10	1.10E-03	7.23E+02	7.12E+02	1.587	
11	1.41E-03	5.65E+02	5.29E+02	6.724	
12	1.77E-03	4.02E+02	4.08E+02	-1.400	
13	2.20E-03	3.41E+02	3.19E+02	6.806	
14	2.80E-03	2.33E+02	2.44E+02	-4.558	
15	3.55E-03	1.82E+02	1.89E+02	-3.787	
16	4.43E-03	1.45E+02	1.50E+02	-3.082	
17	5.64E-03	1.10E+02	1.18E+02	-6.761	
18	7.13E-03	8.95E+01	9.35E+01	-4.220	
19	8.81E-03	7.70E+01	7.66E+01	0.535	
20	1.10E-02	6.54E+01	6.29E+01	3.926	
21	1.41E-02	5.27E+01	5.06E+01	4.130	
22	1.80E-02	4.11E+01	4.16E+01	-1.304	
23	2.22E-02	3.55E+01	3.53E+01	0.745	
24	2.85E-02	3.00E+01	2.95E+01	1.672	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY. 24 DATA POINTS. RAMP: 170.0 MICROSEC. DATA: CP1
2304 001N 001E Z OPR XTL H 6 8+100
Ch.21 = 0.17 Ch.22 = 0.089 Ch.23 = 16 Ch.24 = 9
RMS LOG ERROR: 2.78E-02. ANTILOG YIELDS 6.6071 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.91		
P 2	-0.03	0.93	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1

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EXAMPLE DATA SET
CAL-PACIFIC INTERNATIONAL, INC.
South Kona, Island of Hawaii

PROJECT NO: 91021 Figure 3-2

4.0 RESULTS AND INTERPRETATION

4.1 GENERAL

The results of the interpretations of individual soundings is the resistivity layering of the subsurface. Where these measurements are taken relatively close together, the results of these individual soundings can be plotted to construct a geoelectric cross-section along a line. From the seven soundings acquired over the area, five were incorporated into a west-east trending geoelectric cross-section. Figure 2-1 shows the location of the individual soundings and the geoelectric cross-section.

To infer from the geoelectric cross-sections geologic and geohydrologic information, characteristic ranges of resistivities are assigned to known local geologic and geohydrologic units. The assigned resistivity ranges for the various units expected in the survey area are shown in Figure 4-1. Since no ash flows, weathered volcanic or intrusive units were interpreted in the cross section, the two main units to differentiate between are the dry unweathered volcanics or fresh-brackish water saturated volcanics and salt water saturated volcanics. In all cases these two units can be separated by their resistivity value in ohm-m and their relative depth of occurrence in the section.

Where a very low resistivity layer (< 5 ohm-m) is detected below sea level, the layer is expected to be caused by salt water saturated volcanics. Static water levels (heads) can subsequently be calculated from these soundings by using the Ghyben-Herzberg principle. This principle states that under conditions of static equilibrium, for every foot of fresh water above sea level there will be about forty feet of fresh water below sea level. An illustration of the Ghyben-Herzberg principle is given in Figure 4-2. This principle, however, assumes static equilibrium and may not apply to TDEM soundings in close proximity to ground water damming structures (i.e., dikes, rifts, etc.).

4.2 GEOELECTRIC CROSS-SECTION

Figure 4-3 shows the results of five TDEM soundings which are presented as a west to east trending geoelectric cross-section. Within the section, layers with similar resistivities have been linked together. Soundings CP1 and CP5 are not included in the cross section but are included on the TDEM interpretation map (Fig. 4-4).

Similar two-layer sequences are interpreted in the geoelectric cross-section for all of the soundings. The upper layer exhibits resistivity values ranging from 288 ohm-m to greater than 5,000 ohm-m. This upper layer is interpreted to represent unweathered volcanics, and where this layer occurs below sea level it is expected to be saturated with fresh-brackish basal water. The lower layer of these five soundings exhibit very low resistivity values ranging from 1.3 to 3.6 ohm-m. This lower layer is interpreted to represent salt water saturated volcanics. The approximate thickness of the fresh-brackish water lens was found to vary from 8 ft at sounding 2, which is relatively close to the shoreline, to 429 ft at sounding CP3 to the east.

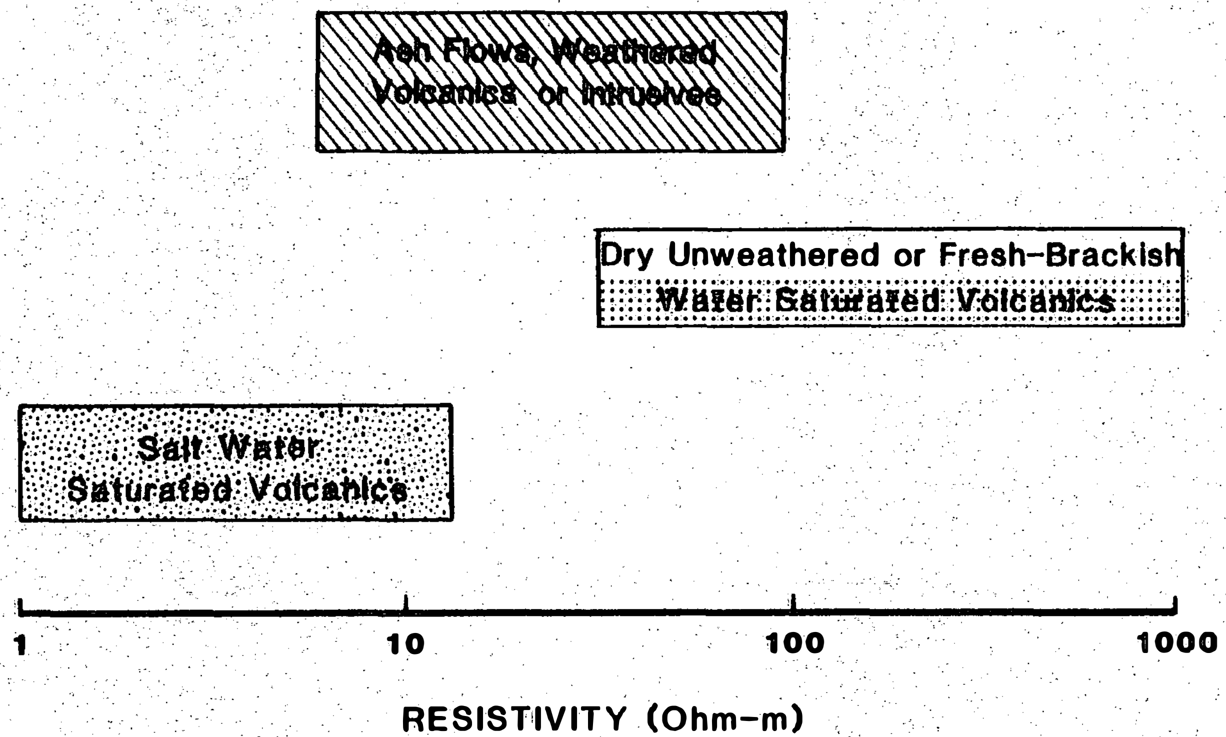
4.3 HYDROGEOLOGIC INTERPRETATION

Table 4-1 lists the thickness of the fresh-brackish water lens calculated from the elevation of the salt water interface interpreted from the TDEM soundings. The table does not include the value of head calculated by using the Ghyben-Herzberg principle.

Table 4-1. **Hydrogeologic information derived from TDEM soundings**

Sounding No. (Survey Year)	Surface Elevation (ft)	Approximate Thickness of Fresh-Brackish Water Lens (ft)
1 (1990)	1180	38 ✓
2 (1990)	880	8 ✓
CP1 (1991)	1460	230
CP2 (1991)	1760	373
CP3 (1991)	2210	429
CP4 (1991)	1480	274
CP5 (1991)	1140	11 ✓

Figure 4-4 shows the geophysical interpretation map for all seven TDEM soundings from both surveys. Information from the interpretation map shows that beneath all of the soundings the fresh-brackish water resource is interpreted to exist in the basal mode. The approximate thickness of the lens was found to be very thin at sounding 2 (8 ft) and increase to 429 ft at sounding CP3.



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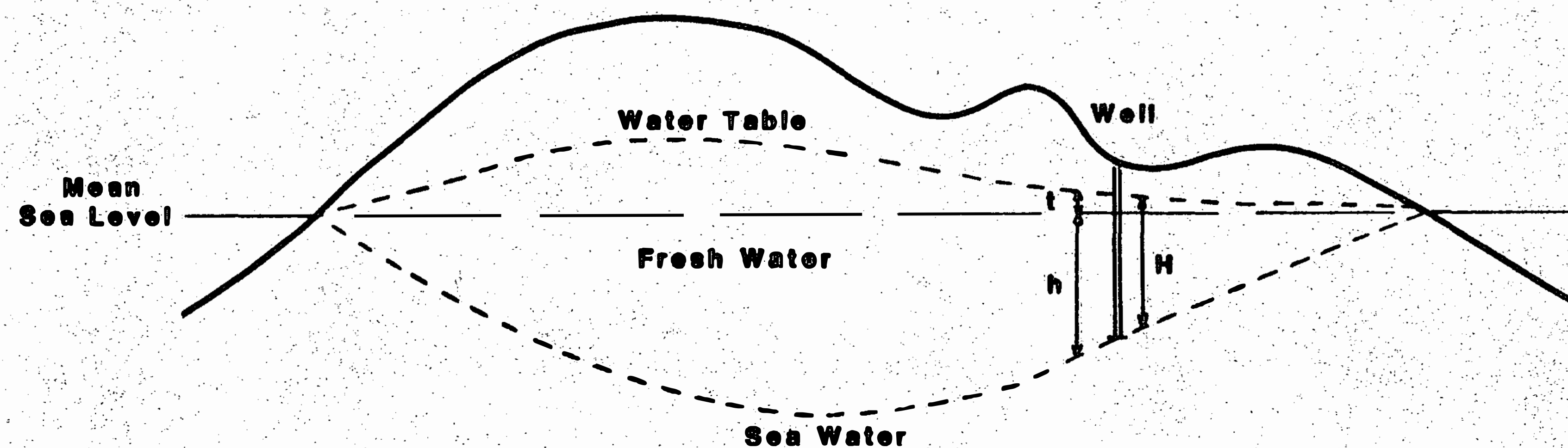
CHARACTERISTIC RESISTIVITY RANGES

CAL-PACIFIC INTERNATIONAL, INC.
South Kona, Island of Hawaii

PROJECT NO: 91021 **Figure 4-1**



$t = 1/40\ (h)$

FROM: HERZBERG

BLACKHAWK GEOSCIENCES, INC.

Illustration of the Ghyben-Herzberg Principle

CAL-PACIFIC INTERNATIONAL, INC.

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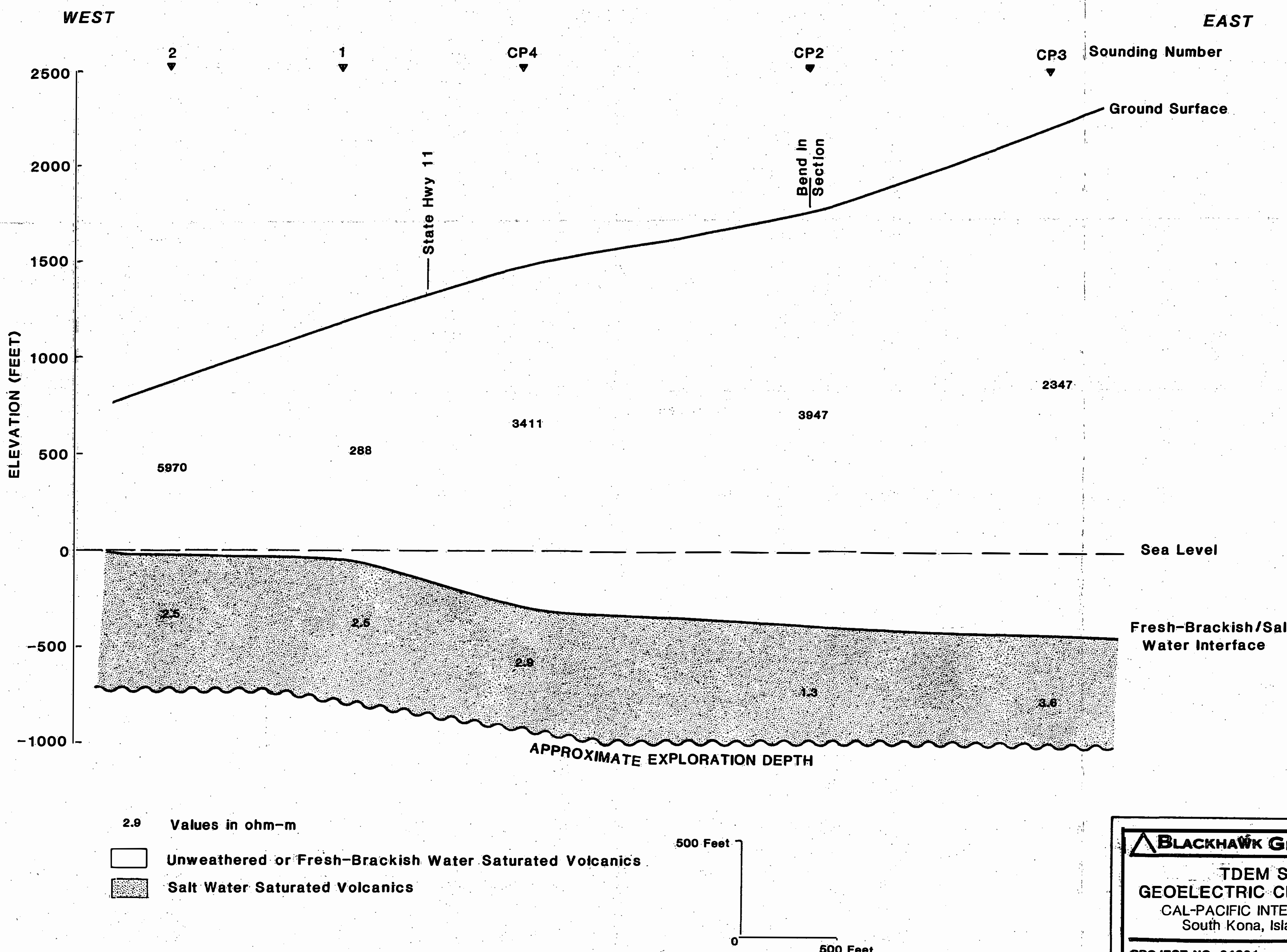
Figure 4-2



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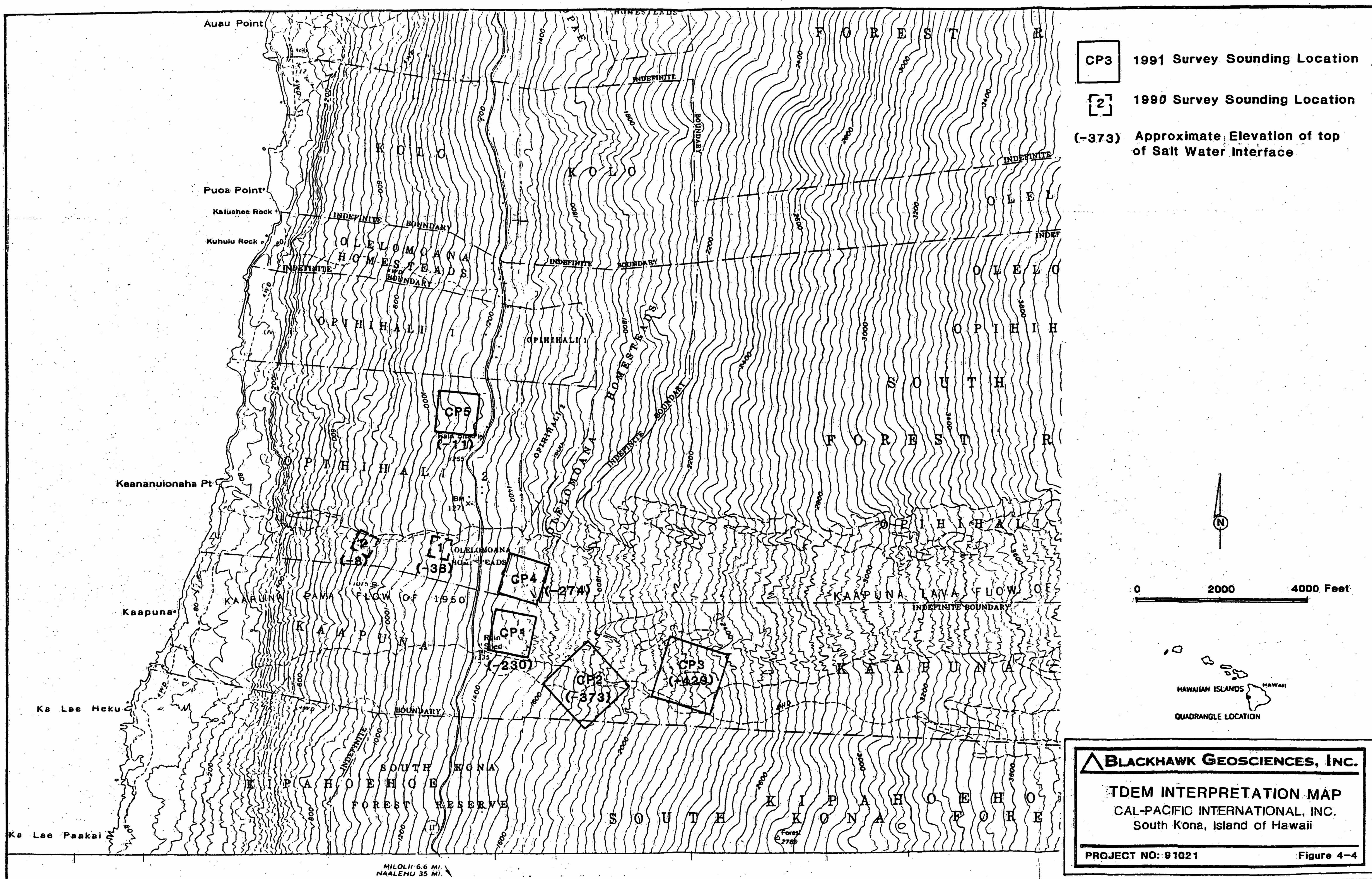
TDEM SURVEY
GEOELECTRIC CROSS SECTION
CAL-PACIFIC INTERNATIONAL, INC.
South Kona, Island of Hawaii

PROJECT NO: 91021 Figure 4-3



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TDEM INTERPRETATION MAP
CAL-PACIFIC INTERNATIONAL, INC.
South Kona, Island of Hawaii

PROJECT NO: 91021

Figure 4-4

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this TDEM survey and the May 1990 survey are summarized in Figures 4-3 and 4-4. Beneath all of the seven soundings the ground water resources are expected to be present as a lens of fresh-brackish water floating on sea water (basal mode). The elevation of the top of the salt water interface derived from TDEM soundings is expected to vary from about -8 ft near sounding 2 to -429 ft at sounding CP3. For soundings 1, 2 and CP5 salt water is interpreted to be very close to sea level (-8 to -38 ft), indicating a thin basal water resource which is most likely brackish. Between sounding 1 and CP4 a rapid increase in depth to top of salt water interface is interpreted. Beneath the group of soundings CP1 through CP4 east of Hwy 11 a water lens a basal fresh water lens is expected, varying from about 230 ft to 429 ft in thickness.

The accuracy in determining the depth to the salt water saturated interface has been previously estimated to be about ± 5% of the total depth measured.